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Secondary Deuterium Isotope Effect and Solvent Effect in the Thermal Rearrangement of 2-Allyloxybenzothiazole and Some Related Compounds*

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Thermal rearrangement of 2-allyloxybenzothiazole, 2-allyloxythiazole and of 2-cinnamyloxybenzothiazole gave the corresponding N-alkenylbenzothiazoline-2-one and N-alkenylthiazoline-2-one in an excellent yield. Normal secondary kinetic isotope effect was observed for 2-allyl-1′,1′-d_2-oxy derivative while the inverse isotope effect was observed for 2-allyl-3′,3′-d_2-oxy derivative. Solvent effect was studied with 2-allyloxybenzothiazole and no significant effect was observed.

The γ-phenyl group in the allyloxy moiety enhances the rate of the rearrangement. On the other hand the introduction of the γ-phenyl or γ-methyl group in the allylthio moiety of the 2-allylthiobenzothiazole retarded the rate of the thermal rearrangement.

INTRODUCTION

In the previous paper, we have reported a kinetic study of the thio-Claisen rearrangement of 2-allylthiobenzothiazole and suggested the ground-state stabilization due to the presence of the sulfur atom as the migration origin.[1)]

This suggestion was made to explain the inverse kinetic isotope effect exhibited by 2-allyl-1′,1′-d_2-thiobenzothiazole.

The above explanation requires quite a different behavior in the corresponding heterocyclic allylic ethers where the ground state stabilization of such kind is absent.

Heterocyclic analogues of the Claisen rearrangement were recently reviewed.[2)] However, little is known about the kinetic behavior of these rearrangements.

In the present paper, we will present the kinetic study of the thermal rearrangement of 2-allyloxybenzothiazole and the related heterocyclic ethers. The thermal rearrangement of alkenylsulfides, 2-(2′-butenylthio)-benzothiazole and 2-(*p*-chlorocinnamylthio)-benzothiazole, were compared with that of the corresponding ether.

RESULTS AND DISCUSSIONS

The standard method was employed for the synthesis of 2-alkenyloxybenzothiazoles, 2-allyloxythiazole and 2-alkenylthiobenzothiazoles.[3)] The properties of the 2-allyloxy-

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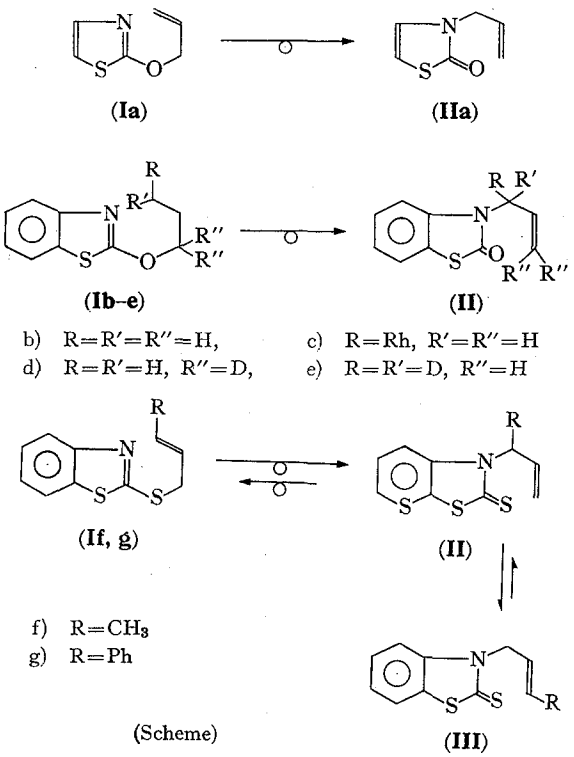
benzothiazole were in good agreement with that reported by Elwood and Gates[3] and the properties of the 2-(2′-butenylthio)-benzothiazole also were in good agreement with that reported by Moore and Waight.[4] 2-Allyloxythiazole, 2-cinnamyloxybenzothiazole and 2-(p-chlorocinnamylthio)benzothiazole were identified by the elemental analysis and by IR or NMR spectra.

On heating the neat sample or a solution in a variety of solvents, 2-alkenyloxybenzothiazoles and 2-allyloxythiazole underwent a thermal rearrangement to N-alkenyl benzothiazoline-2-one and to N-allyl thiazoline-2-one in an excellent yield (Scheme).



(Scheme)

The analysis by a thin layer chromatography (TLC) indicated that these heterocyclic ethers underwent essentially complete conversion to the thiazoline-2-one. Deuterium labeling as well as the rearrangement of 2-cinnamyloxybenzothiazole revealed the complete inversion of the allylic moiety in the rearrangement.

The kinetic study was made by an ampoule technique. After heating for an appropriate time, the starting material and the reaction product were separated by TLC and was analyzed by UV spectrophotometry. A good first-order kinetics held for every run. The results are shown in Fig. 1. First-order rate constants are summarized in Tables I and II.

The secondary deuterium kinetic isotope effect was determined in acetonitrile to ensure the comparison with the effect in the thio-Claisen rearrangement of 2-allylthiobenzothiazole.[1] The isotope effects are summarized in Table III.

The activation parameters for 2-allyloxythiazole obtained in solvent Carbitol show a characteristically low negative entropy of activation and is in accord with that in most

Table I. First-Order Rate Constants and Activation Parameters for the Rearrangements of 2-Allyloxythiazole (Ia), 2-Allyloxybenzothiazole (Ib), and 2-Cinnamyloxybenzothiazole (Ic).

Compounds	Solvent	Temp. (°C)	$k \times 10^5$ (sec^{-1})	ΔH^* (Kcal/mole)	ΔS^* (e.u.)
Ia	Carbitol	130.0	2.50	27.3	−12.4 (140°C)
		140.0	5.80		
		150.0	13.1		
Ib	CH_3CN	120.0	2.68	28.4	− 7.8 (130°C)
		130.0	6.45		
		140.0	16.6		
Ic	CH_3CN	89.0[a]	76.5	20.0[c]	−17.7[c] (100°C)
		100.0[a]	179.0		
		(140.0	7360[b])		

a) Rates were determined by NMR measurements.
b) Extraporated from the rates at different temperatures.
c) Calculated from the rates at only two different temperatures, accordingly, this value is less reliable than that for Ia and Ib.

Table II. Kinetic Solvent Effects. First-Order Rate Constants for the Rearrangement of 2-Allyloxybenzothiazole in a Variety of Solvents at 130.0°C.

Solvent	$k \times 10^5$ (sec^{-1})	Z
Acetonitrile	6.45	71.3
Ethanol	5.04	79.6
Acetone	4.26	65.7
THF	2.96	(71.6)[a]

a) Calculated from $Y_{THF} = -6.073$ by tentatively assuming $Y = 0.4132\,Z - 35.867$. c.f. E. M. Kosower, *J. Amer. Chem. Soc.*, **80**, 3253 (1958).

of the Claisen rearrangement.[5] The magnitude of the entropy of activation for 2-allyloxybenzothiazole is somewhat smaller, but still falls in the expected range.[5]

An interesting observation was made of 2-cinnamyloxybenzothiazole. This compound showed a marked rate enhancement compared with the parent allyl ether, thus the rearrangement took place well below 100°C.

The relative rate of this cinnamyl ether to 2-allyloxybenzothiazole at 140°C can be estimated to be about 1 : 400. Similar rate enhancement by the introduction of phenyl group was also reported for *p*-tolyl alkenyl ethers, although the enhancement was not so significant. White and his co-workers reported that *p*-chlorocinnamyl *p*-tolyl ether rearranged about 4–5 times more rapidly than the allyl p-tolyl ether.[6]

On the other hand, rate retardation observed for p-chlorocinnamylthio derivative and for 2′-butenylthio derivatives is worthy to note. The parent compound allylthio derivative exhibited the first-order rate constant[1] of $3.83 \times 10^{-3}\ min^{-1}$ at 180°C which is fairly close to that of the allyl *p*-tolyl ether[7] ($2.64 \times 10^{-3}\ min^{-1}$ at 181°C). However, in the present work, 2-(*p*-chlorocinnamylthio)benzothiazole underwent the rearrangement

only very sluggishly, and a significant difference was found between cinnamyl ether and the cinnamyl sulfide.*

The secondary kinetic isotope effect at the α-position with respect to the migration origin (oxygen) was normal and about 9.5% per one deuterium atom. At the γ-position, the effect was inverse and the magnitude was about 2.6% per one deuterium atom. Such a trend is in good agreement with the other example of 3,3-sigmatropic rearrangement[9] and the rearrangement of allyl thionebenzoate.[5b]

As shown in Table II, there exists essentially no significant relationship between the solvent polarity and the rate of the rearrangement of 2-allyloxybenzothiazole.**

Secondary kinetic isotope effect and the lack of the definite dependency of the rate

Table III. Secondary Deuterium Isotope Effects for the Rearrangement of 2-Allyloxybenzothiazole in Acetonitrile.

Temp. (°C)	$k_{2H}\times10^5$ (sec^{-1})	$k_{\alpha-2D}\times10^5$ (sec^{-1})	$k_{\gamma-2D}\times10^5$ (sec^{-1})	$k_{2H}/k_{\alpha-2D}$	$k_{2H}/k_{\gamma-2D}$
120.0	2.64	2.24	2.86	1.18	0.92
	2.72	2.26	2.83	1.20	0.96
130.0	6.45	5.45	6.66	1.19	0.97
	6.45	5.18	6.88	1.26	0.94

* 2-2′-Butenylthio) and, especially, 2-(*p*-chlorocinnamylthio)-benzothiazole rearranged very sluggishly at 170–200°C. This is in accord with the results of British authors.[4] At an elevated temperature (230°C), however, 2-(*p*-chlorocinnamylthio)-benzothiazole rearranged with a severe decomposition of both of the product and the starting material. Major product of the rearrangement was N-(*p*-chlorocinnamyl) benzothiazoline-2-thione, a "Chapman" product. The rearrangement product of the 2-(2′-butenylthio) derivative at 230°C was mainly a "Chapman" product, N-2′-butenylbenzothiazoline-2-thione, however, normal "Claisen" product, N-1′-methylthiobenzothiazoline-2-thione, was also isolated in a minor yield.

In the rearrangement of 2-(2′-butenylthio)benzothiazole conducted in acetonitrile as well as in the rearrangement of the neat sample, the amount of the "Claisen" product was about 4% of the total rearrangement product at a higher conversion. While at about 10% conversion in acetonitrile solution, the "Claisen" product was estimated to be about 15% of the products and the relative amount of this "Claisen" product decreased with the progress of the reaction.

When the ion-pair mechanism is operative, the partitioning of the carbonium ion should be determined essentially by the reactivity inherent to the alkenyl cation. Thus the product ratio should remain constant all through the rearrangement provided the ion-pair mechanism is the sole path-way or is the one of the competitive first-order pathways. As it is pointed out, this was found not to be the case.

This is the indication against the mechanism that involves the allylic carbonium ion or a free radical.[1,4]

The origin of the "Chapman" product should be ascribed to a consecutive rearrangement of the "Claisen" product. A facile 1,3-scrambling on nitrogen atom thus leading to more stable isomer is observed by Y. Makisumi of Shionogi and Co., Ltd. We are grateful to Dr. Makisumi for furnishing us his result prior to publication.

A 1,3-scrambling on the sulfur atom also should be taken into account to rationalize the formation of the "Chapman" product. The "Claisen" product from this 1,3-scrambled sulfide is identical with the "Chapman" product from the original sulfide. 1,3-Scrambling of the allylic sulfide, ether or amine was reported by Kwart.[8]

** Linear regression analysis of the results in Table II gave r=0.20, which indicated the essential absence of the correlation between rate constants and Kosower's Z-value.[10]

of the rearrangement on the solvent polarity indicate a very poor ionic nature of this rearrangement and these results suggest that these reactions proceed through a concerted mechanism.

With the common feature of a concertedness of the reaction, the contrast between thio-Claisen and the Claisen rearrangements in the similar heterocyclic system is noteworthy. The rate-retardation caused by the introduction of γ-phenyl group and the inverse isotope effect at the α-position to the migration origin, which were the characteristics of the thio-Claisen rearrangement,[1] were absent in heterocyclic allyl ethers.

Rate retardation by a phenyl group (and/or by a methyl group) might be ascribed to the steric hindrance to the approach of the allylic double bond to the migration terminus. However, such an effect should be quite similar to both the sulfide and the ether, and the steric hindrance could not be a major factor that caused a significant rate retardation.

Accordingly, two contrasting features should result from the presence of the sulfur atom. Thus the suggestion of the ground state stabilization seems to have a support.

The results obtained in the present study are all coincide with the view that the oxygen-to-nitrogen thermal rearrangement of the allylic moiety in 2-alkenyloxybenzothiazoles and in 2-alkenyloxythiazole can be classified as Claisen rearrangement.

EXPERIMENTAL

Materials: All the compounds described gave satisfactory elemental analysis, IR and NMR spectra. Spectral properties* are summarized in Tables IV and V.

2-Allyloxythiazole (Ia). 2-Bromothiazole (14.5 g, 0.088 mole) prepared by the method of Ganapathi,[11] was added to the solution of sodium allyloxide in allyl alcohol (4.1 g of sodium metal in 150 ml of allyl alcohol) at 20°C. After the addition was over, the reaction mixture was kept at 90°C for 3 hr. The reaction mixture was cooled to room temperature and was filtered. The filtrate was concentrated in vacuo and the oily residue was taken up in ether. Ethereal extract was washed with water and was dried with anhydrous magnesium sulfate. After concentration and distillation under reduced pressure, 2-allyloxythiazole was obtained as a colorless liquid. 4.0 g (32%) bp 48°C/3 mmHg.

2-Allyloxybenzothiazole (Ib) and *2*-Cinnamyloxybenzothiazole (Ic). These compounds were prepared after Elwood and Gates.[3] Ib; yield 36% bp 75–76°C/1 mmHg. Ic; yield 40% mp 89–90°C.

2-Allyl-1′,1′-d^2-oxybenzothiazole (Id). To a suspension of 0.6 g (0.013 mole) of sodium hydride in 25 ml of dry ether was added 0.8 g (0.013 mole) of allyl-1,1-d_2-alcohol.[12] After the evolution of hydrogen ceased, 2.5 g (0.015 mole) of 2-chlorobenzothiazole was added and the reaction mixture was stirred for two days at room temperature. The ethereal solution was then washed with water (50 ml) and dried with anhydrous magnesium sulfate. Ether was removed in vacuo, and the residue was dissolved into 50 ml of toluene containing 3.5 g (0.04 mole) of piperidine to remove the unreacted 2-

* NMR spectra were obtained with a JEOL 3H-60 or a PS-100 spectrometer using carbon tetrachloride as the solvent. Peak positions are expressed in parts per million from TMS. Infrared spectra were taken with a JASCO DS-402G spectrometer (liquid film), and are given in wave numbers (cm^{-1}). The ultraviolet spectra were measured in chloroform solution with SHIMADZU QV-50 spectrophotometer.

chlorobenzothiazole. After stirring overnight at 50°C, the toluene solution was filtered and concentrated under reduced pressure. The residue was poured into cold water and the organic layer was extracted with ether. Concentration and distillation under reduced pressure gave 0.6 g (23%) of colorless liquid. bp 81°C/2 mm Hg. 2-Allyl-3′,3′-d_2-oxybenzothiazole (Ie) was prepared in the same way. yield 30%'

2-(p-Cl-Cinnamylthio) benzothiazole (Ig). To a solution of sodium benzothiazole-2-thiolate (0.01 mole) in 50 ml of acetonitrile, equimolar amount of *p*-Cl-cinnamyl bromide in 20 ml of acetonitrile was added dropwise at 5–10°C. The resulting mixture was stirred overnight at room remperature and filtered to remove the precipitated sodium bromide. The filtrate was concentrated in vacuo and the resulting residue was poured into ice-water. The organic compound was taken up in ether. The ethereal extract was dried with anhydrous magnesium sulfate and was concentrated to give colorless crystal. Recrystallization from *n*-hexane gave 2.5 g (78%) of colorless crystal (mp. 101.5–102.5°C).

Anal. Calcd for $C_{16}H_{12}NS_2Cl$: C, 60.46; H, 3.81; S, 20.18 (%)
Found: C, 60.74; H, 4.07; S, 20.06 (%)

(If) was prepared in the same way. Yield 81%.

N-Allyl thiazoline-2-one (IIa). Under nitrogen at 140°C, 2.6 g of (Ia) was heated in a sealed tube. After 6 hours, the rearrangement was complete. Distillation under

Table IV. Summary of the Spectroscopic Data for the 2-Alkenyloxy(benzo)thiazoles (Ia, b, c, f, g)

Compound	IR Spectrum (cm^{-1})	NMR Absorption (δ ppm)	UV Spectrum λ_{max} (nm) (ε)
Ia	1515 (s)	4.88 (d, $-CH_2-O-$) 5.32 (m, $=CH_2$) 6.05 (m, $-CH=$) 6.85 (q, aromatic)	243 (4760)
Ib	3080 (m), 2990 (w) 2960 (w), 2910 (m) 2824 (w), 1645 (m) 1530 (s), 1435 (s) 1410 (m), 1348 (m) 1320 (s), 1060 (s) 1010 (m), 960 (s) 920 (s), 745 (s) 720 (m),	5.01 (d, $-CH_2-O-$) 5.37 (m, $=CH_2$) 6.06 (m, $-CH=$)	298 (903)
Ic	1520 (s) 965 (s)	5.15 (d, $-CH_2-O-$) ca. 7.5 (m, $-CH=CH-$) 7.7–7.0 (m, aromatic)	
If	1665, 961	1.37 (d, $-CH_3$) 3.92 (d, $-CH_2-$) 5.75 (m, $-CH=CH-$)	291 (1.182×10^4)
Ig	1660 962	4.25 (d, $-CH_2-$) 6.50 (m, $-CH=$) 6.72 (d, $=CH-Ph$)	302 (1.827×10^4) 292 (2.205×10^4)

reduced pressure gave 0.6 g (23%) of colorless liquid. bp 71°C/0.35 mm Hg. Similarly, N-allylbenzothiazoline-2-one (IIb), N-1′-phenylallylbenzothiazoline-2-one (IIc), N-allyl-3′,3′-d_2-benzothiazoline-2-one (IId), and N-allyl-1′,1′-d_2-benzothiazoline-2-one (IIe) were prepared. IIb, bp 102°C/0.2 mmHg; IIc, mp 64.5–65°C.

N-(p-Cl-cinnamyl) benzothiazoline-2-thione (IIIg). About one gram of the neat sample of Ig was placed in a tube and was sealed under nitrogen. The sealed tube was heated at 200°C for 3 hr. in a thermostated bath. The resulting content was analyzed by TLC to show that the rearrangement proceeded only slightly. Then the sealed tube

Table V. Summary of the Spectroscopic Data for the N-Alkenyl (benzo)thiazoline-2-one (IIa, b, c, d, e)

Compound	IR Spectrum (cm^{-1})	NMR Absorption (δ ppm)	UV Spectrum λ_{max} (nm) (ε)
IIa	1650 (s)	4.29 (d, $-CH_2-N-$) 5.21 (m, $=CH_2$) 5.89 (m, vinyl) 6.46 (g, ring)	244 (6254)
IIb	3030 (w), 2950 (w) 2890 (w), 1660 (s) 1580 (m), 1460 (s) 1425 (m), 1300 (s) 1175 (s), 1120 (m) 980 (m), 915 (s) 732 (s), 655 (m)	4.47 (d, $-CH_2-N-$) 5.16 (m, $=CH_2$) 5.80 (m, $-CH=$) 7.10 (m, aromatic)	291 (3286)
IIc	1650 (s),	5.35 (m, $-CH_2-N-$) ca. 6.4 (m, $-CH=$) 6.45 (m, $-CHPh=$) 7.4–6.6 (m, aromatic)	
IId	2300 (w) 2190 (w) 1115 (w) 1032 (w)	(5.16 absent) 5.80 broad	
IIe	2300 (w) 2120 (w) 1000 (m)	(4.47 absent) 5.80 (m)	
IIf		1.66 (d, $-CH_3$) 5.35 (m–q, $=CH_2$) 5.98 (m, $-CH)=$ 66.05 (m, N–CH–)	329 (2.873×10^4) 243 (1.494×10^4)
IIIf	1670 (s)	1.75 (d, $-CH_3$) 5.02 (d, $-CH_2-$) 5.75 (m, CH=CH)	
IIIg	1655 (s) 960 (s)	5.35 (m, $-CH_2-$) 6.42 (m, $-CH=$) 6.72 (d, $-C=CH-Ph$)	330 (3.277×10^4)

was heated again at 230°C for 6 hr. The resulting brown mixture contained many decomposition products along with starting material and the rearrangement product. The reaction mixture was chromatographed on silica-gel using benzene-hexane mixture (1 : 1) as an eluant. The product was isolated and was recrystallized from *n*-hexane to give 0.28 g (38%) of colorless crystal (mp 161.0–161.5°C). N-(1′-methyl-2′-propenyl) benzothiazoline-2-thione (IIf) and N-2′-Butenyl benzothiazoline-2-thione (IIIf). The reaction mixture from 2-(2′-butenylthio)-benzothiazole (If) was repeatedly developed on a silica-gel thin-layer to give a good separation of the products. The relative amount of these two products was determined by UV-spectrophotometry assuming the common molar extinction coefficient for both of the products. (λ_{max}; 329 nm, ϵ; 2.873×10^4).

Kinetic Measurement: Rates were followed by the ampoule technique. 2-Alkenyloxybenzothiazole or 2-allyloxythiazole was accurately weighed in a 10 ml volumetric flask and was diluted with an appropriate solvent to give about 0.06–0.065 M solution. One half ml aliquots were transferred into the ampoule flushed with nitrogen. Ampoules were heated in a thermostated bath and were withdrawn at intervals. After cooling, the starting material and the rearrangement product were separated by TLC on silica-gel. A mixed solvent of *n*-hexane-benzene (2 : 1) was used except for Ia–IIa mixture where chloroform was the effective eluting solvent. When the separation was achieved, I and II were extracted with five 2 ml portions of reagent grade chloroform and the extracts were made up to 10 ml, and the amount of these two compounds were determined spectrophotometrically. As the rearrangement was complete in every case, the first-order kinetics was assumed and the excellent fit was obtained.

The bath temperature was maintained within 0.05°C of the specified value. The error of the individual rate measurement was smaller than 1% and the reproducibility

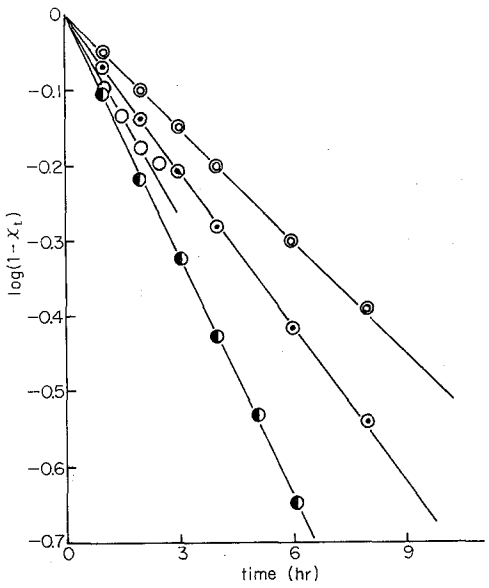


Fig. 1. Rate plots for the Rearrangement of 2-allyloxybenzothiazole (Ib) in a variety of solvents (at 130.0°C).

of the duplicate run was acceptable, the variation being about 2% or better. Thus the error in $\Delta H^{\ddagger}$ and $\Delta S^{\ddagger}$ were estimated not greater than 0.5 Kcal/mole or 1 e.u. respectively.

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REFERENCES

(1) T. Takahashi, A. Kaji and J. Hayami, a paper submitted to this Bulletin, the preceding paper.
(2) (a) B. S. Thyagarajan, *Advan. Heterocyclic Chem.*, **8**, 143 (1967); (b) M. Chanon, M. Conte, J. Micozzi and J. Metzger, *Intern. J. Sulfur Chem., C***6**, 85 (1971); (c) E. Winterfeld, "Fortschritte der Chemischen Forschung", Band 16, Heft 1, 75 (1970).
(3) J. K. Elwood and J. W. Gates, Jr., *J. Org. Chem.*, **32**, 2956 (1967).
(4) C. G. Moore and E. S. Waight, *J. Chem. Soc.*, (1953), 4237.
(5) (a) W. N. White and E. F. Wolfarth, *J. Org. Chem.*, **35**, 2196 (1970); (b) K. D. McMichael, *J. Amer. Chem. Soc.*, **89**, 2943 (1967).
(6) W. N. White and W. K. Fife, *ibid.*, **83**, 3846 (1961). and references cited therein,
(7) W. N. White, D. Gwynn, R. Schlitt, C. Girard and W. Fife, *ibid.*, **80**, 3271 (1958).
(8) H. Kwart and N. Johnson, *ibid.*, **92**, 6064 (1970).
(9) K. Humski, R. Malojcic, S. Borcic, and D. E. Sunko, *ibid.*, **92**, 6534 (1970).
(10) E. M. Kosower, *ibid.*, **80**, 3243, 3267 (1958).
(11) K. Ganapathi, and A. Venkataraman, *Proc. Indian Acad. Sci., Section A*, 362 (1945).
(12) R. D. Schuetz, and F. W. Millard, *J. Org. Chem.*, **24**, 297 (1959).